Phase I

Monthly Progress Report

June 14, 1996
Report No. 2
Reporting Period: May 11, - June 12, 1996

CONTRACT TITLE AND NUMBER:
"Advanced Monitoring of Groundwater Cleanup Technologies" - Phase I
F41624-96-C-0006

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CONTRACT PERIOD:
April 19, 1996 - October 4, 1996

TASK 1 - DESIGN AND CONSTRUCT MINIATURE LONG PATH GAS CELL

Objective: To develop a multi-pass gas cell with maximum pathlength and minimum volume employing On-Line's patented non-spherical, aberration-correcting optics.

Summary of Progress: Ray tracing analysis for the proposed small volume, long optical pathlength gas cell was completed. The analysis has resulted in a design which meets the 500 cc gas volume constraint for the cell, while preserving the optical image quality over a suitably long pathlength. The analysis has indicated that a 50 meter effective pathlength is possible within the small volume constraint.

The analysis traces light rays backwards through the optical system from the detector to the source. This point of view allows the optics to be analyzed (and optimized) for the light rays which actually can be received by the detector, dependent on size and exceptance cone angle, rather than study all of the light which originates from the source, Figure 1, for example, illustrates the need to preserve the image in a multi-pass cell. The optics layout shown in Fig. 1a shows the principal ray starting at the detector to enter the cell then reflect between objective and field mirrors until it exits the cell to be directed to the source. Figures 1b-d show one input image and two output images. The box around each output image is the limit of the cells exit aperture. These particulate images are rays from five points on the square detector (the four corners plus the center) at sixteen field angles, fifteen rays on the extreme cone of view plus one ray at the center of the cone of view. In the case of Fig. 1c, the output image is extremely distorted and enlarged. Such an image is vignetted by the output aperture, resulting in reduced throughput. The exit aperture cannot be merely increased in size because this also increases the space required between images on the field mirror and thus reduces the number of traversals possible. The output image in the case of Fig. 1d is still distorted, but it is not significantly enlarged and throughput is not reduced by the output aperture. This is the condition which has been met previously by AFR/On-Line for 5 meter and 20 meter effective pathlength cells of 1.5 liter volume which utilize an aspheric optical design

Table 1 presents a data spreadsheet for the analysis with aspheric optics to determine if a 60 meter effective pathlength can be achieved within a cell volume limited at 500 cc. For the cases shown, 60 meters could be achieved for several different combinations of number of reflections, separation distance between field and objective mirrors, and diameter of objective mirrors, but 500 cc cell volume did not prove feasible. The analysis did converge to 500 cc volume for 50 meter effective pathlength, with good optical throughput, however. For the number of reflections necessary (in the 200 range) the signal/noise ratio will not differ appreciably between 50 meter and 60 meter lengths, even for highly reflective surfaces (please see Fig. 1 of Progress Report #1). It was decided to proceed with the 50 meter pathlength at the 500 cc volume limit.

Figure 2 presents the theoretical images for the 50 meter cell as they are directed across the surface of the field mirror. The input and exit images are located on the same side of the field mirror, and a pair of flat "step" mirrors at the opposite side produce two row pairs of reflections to achieve the pathlength. The input image consists of 16 points (4 x 4 grid) from the area of a typical 0.250 mm x 0.250 mm detector element. The analysis indicates that the image becomes somewhat distorted through its travel, but is adequately corrected when it gets to the location of the exit aperture.

Based on the performed analysis, CAD drawings for overall dimensions and optical surface definition were made for both field and objective mirrors. These are presently being submitted for price quote and delivery time at two vendors experience in diamond machining for optical surfaces. The choice of vendor will be heavily dependent on delivery time of components due to the time limit of this project.

The geometry of the gas cell body was also considered during this reporting period. The complexity and tight packing of the folded beam requires that two pairs of flat mirrors be

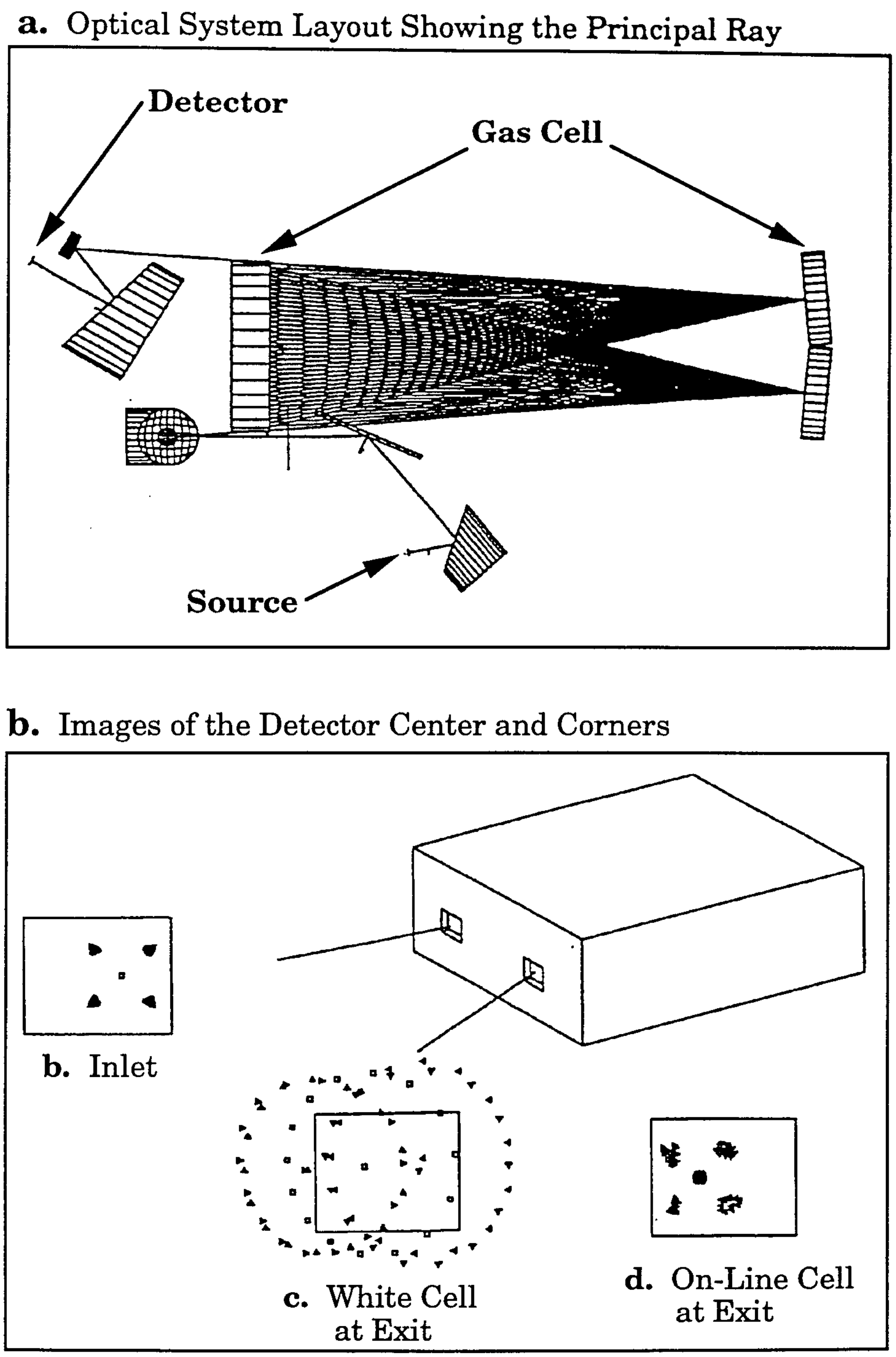

Figure 1. Optical System of the Proposed Gas Cell and Comparison of Performance to a White Cell.

TABLE 1

DATA SPREADSHEET INDICATING CELL PATHLENGTH VS CELL VOLUME (Detector Size 0.250 x 0.250 mm and View Angle 30.00°)

Reflectivity = 99.7%
Maximum Volume = 500 cc

PATH	N-TOT	L, M	IMAGE, MM	D, MM	D-REQ, MM	VOL, CC	THRU
60	200	0.300	2.500	33.000	33.590	661	0.5516
60	200	0.300	2.500	38.000	33.590	767	0.5516
60	200	0.300	2.400	33.000	34.788	635	0.5516
60	216	0.278	2.400	32.000	32.389	594	0.5257
60	232	0.259	2.400	30.000	30.320	542	0.5011
60	232	0.259	2.000	35.000	35.521	533	0.5011
60	340	0.176	2.400	30.000	21.452	472	0.3622
60	240	0.250	2.400	29.500	29.390	526	0.4892
50	200	0.250	2.400	30.000	29.390	481	0.5516
50	192	0.260	2.500	30.000	29.487	510	0.5650
50	192	0.260	2.400	30.000	30.514	489	0.5650
50	192	0.260	2.400	30.500	30.514	489	0.5650

Path = effective pathlength, m
N-TOT = # of reflections
L = distance between mirrors, m
Image = image size, mm
D = input diameter of objective mirror, mm
D-REQ = Calculated requirements for diameter of objective mirror, mm
VOL = required cell volume, cc
THRU = optical throughput based on reflectivity of 99.7%

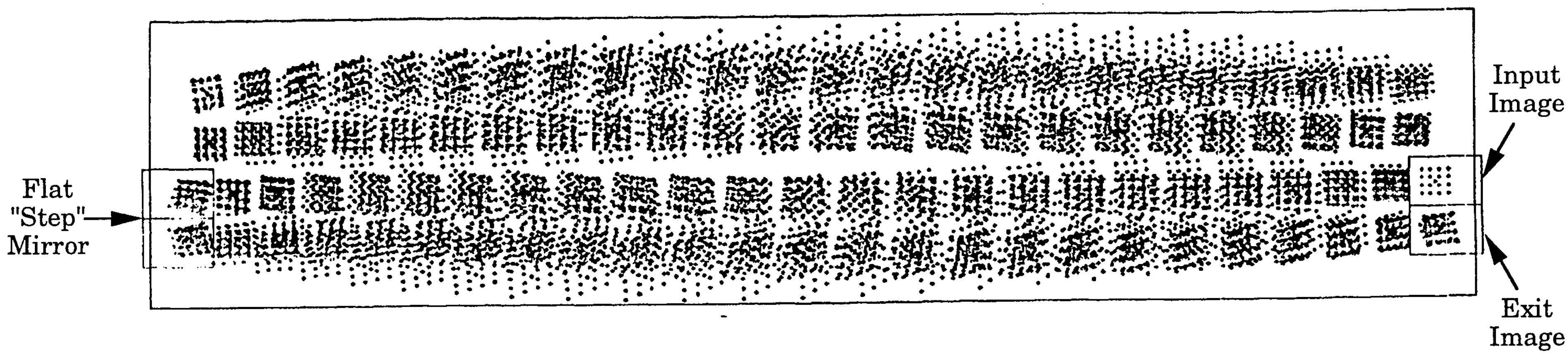

Figure 2. Predicted Image Distortion through Proposed Small Volume, Long Optical Pathlength Gas Cell. Shown are the 96 Reflected Images on the Field Mirror, Plus the Input and Exit Images. The Flat "Step" Mirrors Double the Rows of Reflected Light from Two to Four.

precisely positioned in the cell: 1) a pair of mirrors to "step" the beam to produce two row pairs; and 2) a pair of mirrors to direct the input image appropriately upon entering the cell, and direct the exit image appropriately out of the cell. To locate these mirrors precisely, manual alignment through the cell body wall will be necessary in Phase I. In Phase II, permanently aligned mirrors should be possible with machined flats onto the field mirror. Two ports on one side of the cell will allow the placement of assemblies to position the mirrors. The opposite side of the cell body will be built with a removable panel to allow visual access to the flat mirrors and to an alignment laser beam on the mirrors. A preliminary schematic of the gas cell when coupled to the FT-IR spectrometer is shown in Fig. 3, with arrows indicating the sides which will exhibit the access panel and mirror adjusters. The schematic presents a top view, with the back of the objective mirror labeled as "gas cell". Also shown is a kinematically mounted flat mirror to direct the alignment laser beam (red HeNe) into the optical path. The mirror adjusters will require positional movement in several directions. Designs are presently being considered which will allow the necessary movement while maintaining a gas tight seal.

Plans and Objective for Next Reporting Period: Drawing for gas cell mirrors will be submitted to the chosen diamond machining vendor as soon as possible. Designs of the gas cell body with positioning devices for the small beam steering mirrors will be finalized, and submitted to shops for fabrication.

TASK 2 - COUPLE MINIATURE GAS CELL TO ADVANCED FT-IR GAS ANALYZER

Objective: To design, purchase and implement the infrared transfer optics to couple the miniature gas cell to a contractor owned FT-IR spectrometer suitable for on-site use.

Summary of Progress: As shown previously in Fig. 3, transfer optics (mirrors) direct the IR beam from the spectrometer into the gas cell, and additional mirrors collect the IR beam at the exit of the cell and direct it to the detector. The transfer optics must have focusing characteristics that result in a defocused imaged of a size which matches the size of the objective mirrors of the gas cell. If the image overfills the objective mirrors, IR energy is wasted thus reducing S/N. This is generally the case for commercially available cells unless careful consideration to transfer optics is given.

Now that the cell geometry has been defined, the transfer optics can be specified.

Plans and Objective for Next Reporting Period: Specify and order transfer optics. Specify and order support plate to support the Phase I system.

TASK 3 - TEST SYSTEM RESPONSE AND DETECTION LIMITS TO TRICHLOROETHYLENE CONTAMINATION

Objective: The Phase I monitor will be demonstrated for measurement sensitivity and speed during TCE monitoring.

Summary of Progress: No work performed under this task.

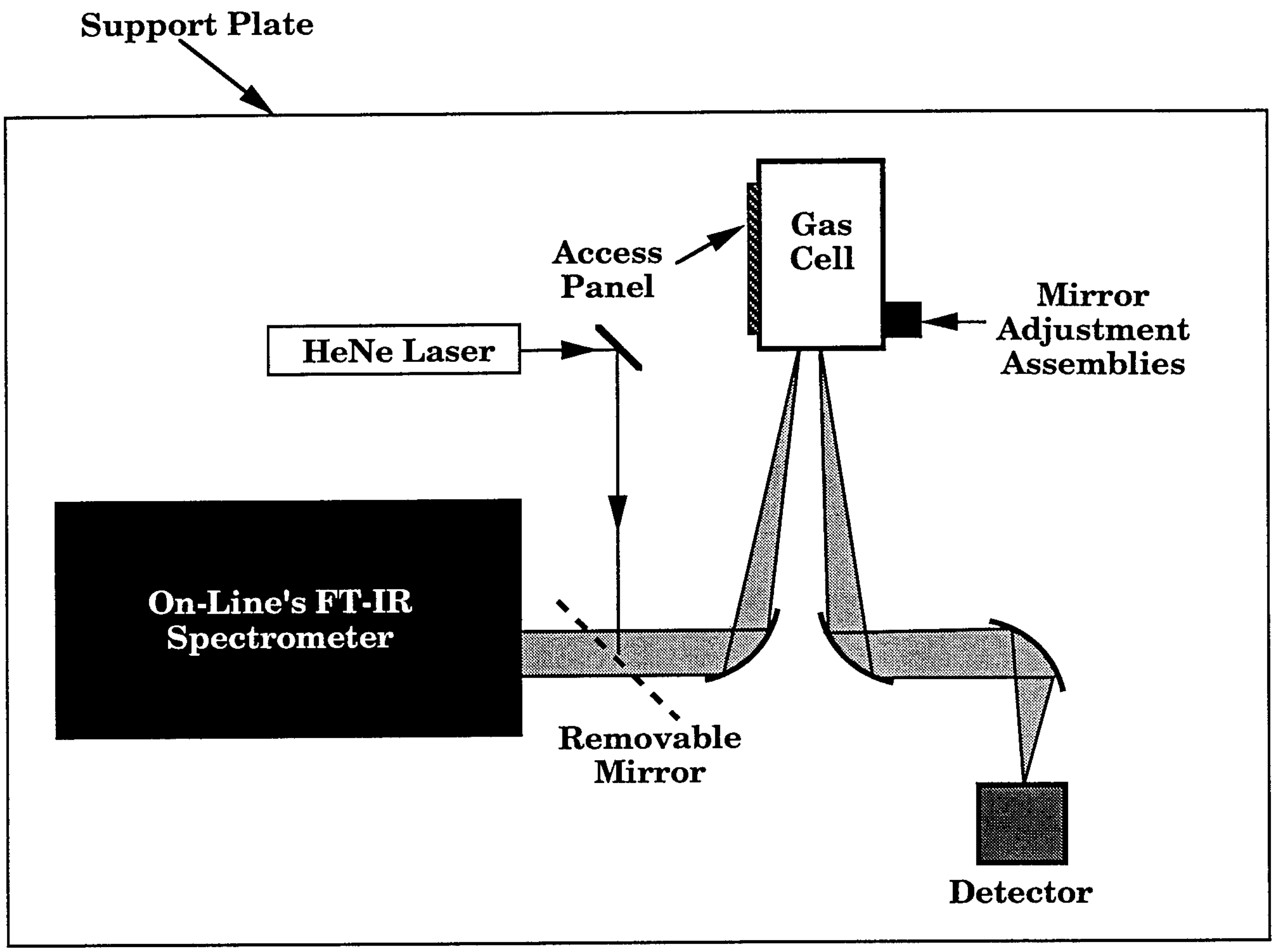

Figure 3. Preliminary Schematic (top view) of Advanced Gas Cell Coupled to On-Line's FT-IR Spectrometer. Overall Footprint is Approximately 15" x 25".

Plans and Objective for Next Reporting Period: Order TCE standard (certified) in preparation for testing.

TASK 4 - PLAN FOR PHASE II PROTOTYPE

Objective: To evaluate the degree to which the overall Phase I objective was met and to formulate a preliminary design for a Phase II prototype

Summary of Progress: No work performed under this task.

MEETINGS AND/OR IMPORTANT TELEPHONE DISCUSSIONS

The Air Force Project Engineer (Bruce Nielsen) was on-site at AFR for the day of June 11, 1996. The program goals and progress to date were reviewed with Jim Markham, Chad Nelson, and David Wright. Expressed by the AF Project Engineer was the need by the AF for an instrument that can monitor a range of airborne chemicals, including complex species associated with AF paint formulations, and emissions in jet engine exhaust. AFR is to receive a list of present species of interest from the AF Project Engineer.

STATUS OF PROPOSED WORK SCHEDULE

	Months						
	0	**1**	**2**	**3**	**4**	**5**	**6**
Task 1 - Design and Construct Miniature Long Path Gas Cell		1		2			
Task 2 - Couple Miniature Cell to Advanced FT-IR Gas Analyzer			3		4		
Task 3 - Test System Response to Trichloroethylene Contamination						5	
Task 4 - Plan for Phase II Prototype							6

Milestones

1 - Test and design completed
2 - Cell fabricated
3 - Coupling optics ordered
4 - System completed
5 - TCE tests completed
6 - Analysis completed

The design of the cell mirrors was completed at the 2 month mark, putting the program about 2 weeks behind the proposed schedule. There is concern that the shop which is to fabricate the cell mirrors will not meet our anticipated schedule. This will be known with certainty in the beginning of the next reporting period.

James R. Markham

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